

# Design of Wheeled Mobile Robot with Tri-Star Wheel as Rescue Robot

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**Abstract**— This study aims to design, and analyze a mobile robot that can handle some of the obstacles, they are uneven surfaces, slopes, can also climb stairs. WMR in this study is Tri-star wheel that is containing three wheels for each set. On average surface only two wheels in contact with the surface, if there is an uneven surface or obstacle then the third wheel will rotate with the rotation center of the wheel in contact with the leading obstacle then only one wheel in contact with the surface. This study uses the C language program. Furthermore, the minimum thrust to be generated torque of the motor and transmission is 9.56 kg. The results obtained by calculation and analysis of DC motors used must have a torque greater than 14.67 kg.cm. Minimum thrust to be generated motor torque and the transmission is 9.56 kg. The experimental results give good results for robot to moving forward, backward, turn left, turn right and climbing the stairs.

**Index Terms**—WMR, tri-star, kinematics, dynamics model.

## I. INTRODUCTION

Wheeled mobile robots (WMR) are generally used for flat areas or smooth trajectory, then the region with a significant height difference then the robot will stop or be programmed to turn look for another way. One of the unique and multifunctional robots are made to address the issues above are a robot with wheels arranged in a triangular shape, so there are three sets of wheels each wheel. This model is commonly called tri-star wheels.

On average surface only two wheels in contact with the ground, if there is an uneven surface or obstacle then the third wheel will rotate with the rotation center of the wheel in contact with the leading obstacle then only one wheel in contact with the surface. This kind of robot that uses wheels contacted to the ground, commonly used on uneven road surfaces. And also, these types of robots are very well used to climb the stairs.

Several previous studies which can be used as a reference, i.e. design rescue robot [1], and design wheel chair that can be climbing the stairs [2]. Meanwhile, this research aims to design and analyze the performance of a mobile robot using a tri-star wheels.

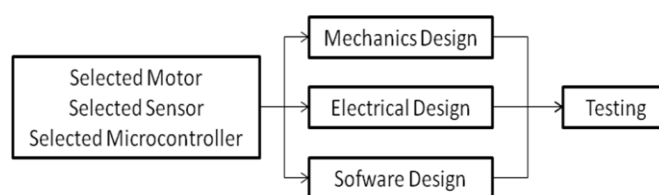


Figure 1. Design of robot

## II. THE CONCEPT OF TRI-STAR

### A. Stages of creating robot

In the Figure 1, shows stages of the manufacturing. There are three stages of manufacture of the robot, the first is planning, Including the selection of hardware and design, the next stage of manufacture, Including the manufacture of mechanical, electronic, and programs, and the last stage is the testing [3].

### B. Wheeled Mobile Robot

Some types of wheels are often used on WMR among other types of Bi-wheeled form of a pair of wheels that can be moved with a soft, very suitable for modeling, but still prone to the risk of slippage. Caterpillar type, form two pairs of wheels (each wheel connected to each other) with the appropriate characteristics of a straight movement, not to risk a skid, but cannot accurately model the turning movement. Type omnidirectional, has characteristics can move freely in all directions throughout the complex structure of the wheel, but still has the disadvantage of frame [4].

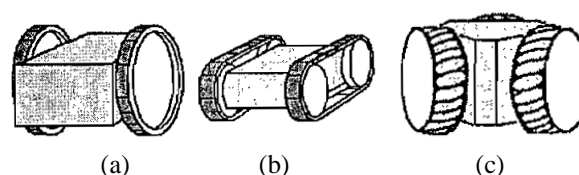


Figure 2. Wheel type that is often used in the WMR  
(a) Bi-Wheel ; (b) Caterpillar ; (c) omnidirectional

### C. Electrical Motor

Wheel of WMR uses an electric motor. For high torque motors and torque motors larger than it is better to use a DC motor. The most important in the selection of a motor is the torque necessary. Note that, Figure 3 shows how the tri-star wheel work. Then, to calculate the minimum torque on the axis robot with the following equation [4]:

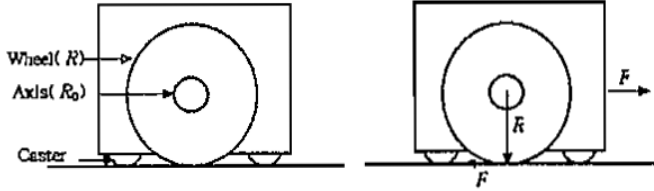


Figure 3. How to calculate torque of motor

Static friction force  $F_r$  on wheels, with a coefficient of static friction between the wheels  $k$  and the robot mass inserta landasan  $\mu$  and  $g$  is the acceleration due to gravity.

$$F_r = \mu \times m \times g \quad (1)$$

Friction Force  $F$ , with radius of wheels  $R$  dan radius of axis is  $R_0$ ,

$$F = F_r \times \frac{R}{R_0} \quad (2)$$

Torque at the axis can be shown,

$$T_G = -F \times R_0 = -\mu \times m \times g \times R \quad (3)$$

Torque of motor is,

$$T_M = \frac{T_G}{(N \times h_G)} = \frac{(\mu \times m \times g \times R)}{N \times h_G} \text{ untuk } (< T_{stall}) \quad (4)$$

where  $h_G$  is an efficiency of gears,  $T_{stall}$  is stall torque, it shown at specification of motor and  $N$  is gear ratio.

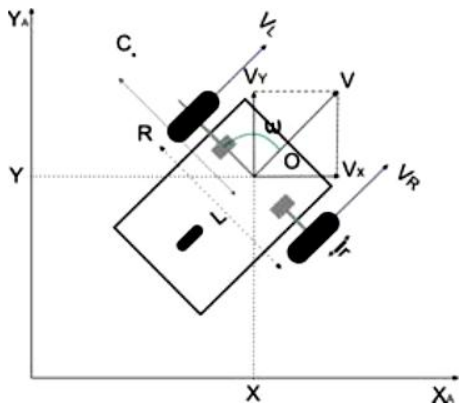


Figure 4. Position and orientation of the mobile robot at Cartesian frame

### A. Kinematics of WMR

Technically, WMR robot has two main wheels are each driven by an independent drive, and the other that there is a wheel with one or two castor wheels. Those wheels are placed at the back of the robot that serves as a counterweight.

Figure 4 shows the architecture of the robot viewed from the top. If both drive wheels are spinning at the same speed, the robot will move straight direction, whereas if one of the wheel speeds is slower, then the robot will move with a curved trajectory toward the direction of one of the wheels that move more slowly [5].

For the wheel radius  $r$ , and the rotation speed of the right wheel, and left respectively  $\omega_R$  and  $\omega_L$  then, the linear speed of the right and left wheels can be calculated by the following equation:

$$v_R(t) = r \omega_R(t) \quad (5)$$

$$v_L(t) = r \omega_L(t) \quad (6)$$

When the robot motion play when time  $t$  with the length of the radius  $R$  is measured from the center of rotation and the center point of the two wheels, the angular velocities can be calculated as:

$$\omega(t) = \frac{v_R}{R + \frac{L}{2}} \quad (7)$$

$$\omega(t) = \frac{v_L}{R + \frac{L}{2}} \quad (8)$$

Robot linear velocity  $v(t)$  and the angular velocity of the robot  $\omega(t)$  can be determined based on both the linear speed of the wheel. In detail, can be shown in matrix presented in equation below,

$$\begin{bmatrix} v(t) \\ \omega(t) \end{bmatrix} = \begin{bmatrix} \frac{1}{2} & \frac{1}{2} \\ \frac{1}{L} & -\frac{1}{L} \end{bmatrix} \begin{bmatrix} v_R(t) \\ v_L(t) \end{bmatrix} \quad (9)$$

This equation shows the relation between the direct kinematics linear velocities of the wheels, and linear and angular velocities of the robot, while this equation below shows the opposite relationship.

$$\begin{bmatrix} v_R(t) \\ v_L(t) \end{bmatrix} = \begin{bmatrix} 1 & \frac{L}{2} \\ 1 & -\frac{L}{2} \end{bmatrix} \begin{bmatrix} v(t) \\ \omega(t) \end{bmatrix} \quad (10)$$

Terms of absolute position control of the mobile robot is a robot knows the position and orientation of each moment. Furthermore, one solution is to calculate the distance the wheel every time. Mileage left wheel ( $S_L$ ), the right wheel ( $S_R$ ), and average distance ( $S$ ) in successive time zones as follows:

$$S_L(t) = v_L(t) \cdot t \quad (11)$$

$$S_R(t) = v_R(t) \cdot t \quad (12)$$

$$S(t) = \frac{v_L(t) + v_R(t)}{2} \cdot t \quad (13)$$

Formula approach to orientation, position coordinates  $x$ , and  $y$  coordinates respectively as follows.

$$\theta(t) = \frac{S_R(t) - S_L(t)}{L} + \theta_0 \quad (14)$$

$$x(t) = x_0 + S \cos \theta(t) \quad (15)$$

$$y(t) = y_0 + S \sin \theta(t) \quad (16)$$

#### D. Tri-star model of WMR



Figure 5. Illustration the movement of Tri-Star Wheel uneven surface

Note, Figure 6 below, gears gear A is connected to the drive. B gears numbering three, connected by gears roda. Dan C is a liaison and steering. All three gears A, B and C are connected to the arm. There are two models of the movement of the WMR by tri-star wheel that is currently running on a flat foundation and up the stairs at the time.

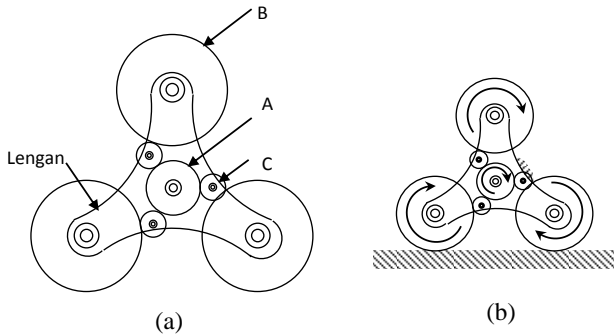


Figure 6. (a) Model of gears of Tri-Star Wheel (b) Moving at flat surface

When moving on a flat surface then, there are two wheels in contact with the runway, each wheel just spins on its axis and each arm is not moving, see figure 6.B. Then, comparison of the angular velocity of the wheels of their gears are

$$\frac{\omega_A}{\omega_C} = \frac{n_C}{n_A} \quad \text{dan} \quad (17)$$

$$\frac{\omega_C}{\omega_B} = \frac{n_B}{n_C} \quad (18)$$

Velocity ratio (N) of this model is

$$N = \frac{\omega_A}{\omega_B} = \frac{\omega_A}{\omega_C} \times \frac{\omega_C}{\omega_B} = \frac{n_C}{n_A} \times \frac{n_B}{n_C} = \frac{n_B}{n_A} \quad (19)$$

When climbing stairs, there is only one wheel in contact with the ground, and the other spinning wheels on the axle in contact with landasan.akibat rotation arm, see Figure 7.a. Kinematics equations under these conditions can be explained

by using the method of complex numbers [7] as follows, note Figure 7.b.

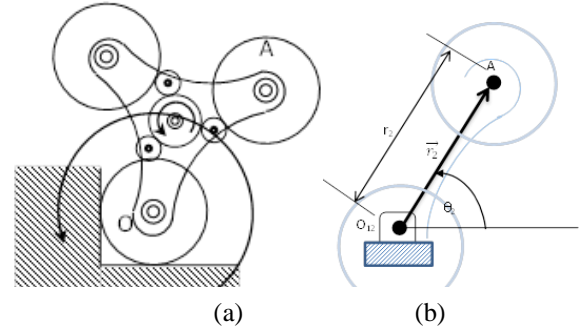


Figure 7. (a) Motion of gears (b) Freebody diagram for A wheel respect to the center A.

position vector of point A is expressed as  $\vec{r}_2$  the following equation form

$$\vec{r}_2 = r_2 e^{i\theta_2} = r_2 (\cos \theta_2 + i \sin \theta_2) \quad (20)$$

If  $\theta_2$  a function of time  $t$ , the velocity of point A is obtained by derivate the A position respect to the time  $t$ .

$$\begin{aligned} V_A &= \frac{d}{dt} (r_2 e^{i\theta_2}) \\ &= i\dot{\theta}_2 r_2 e^{i\theta_2} \\ &= i\omega_2 r_2 (\cos \theta_2 + i \sin \theta_2) \\ &= i\omega_2 r_2 \cos \theta_2 - \omega_2 r_2 \sin \theta_2 \end{aligned} \quad (21)$$

Acceleration of point A obtained by derivate velocity point A respect to time  $t$ .

$$\begin{aligned} A_A &= \frac{d}{dt} (i\dot{\theta}_2 r_2 e^{i\theta_2}) \\ &= i\ddot{\theta}_2 r_2 e^{i\theta_2} - \dot{\theta}_2^2 r_2 e^{i\theta_2} \\ &= i\alpha_2 r_2 (\cos \theta_2 + i \sin \theta_2) - \omega_2^2 r_2 (\cos \theta_2 + i \sin \theta_2) \\ &= i(\alpha_2 r_2 \cos \theta_2 - \omega_2^2 r_2 \sin \theta_2) - \alpha_2 r_2 \sin \theta_2 - \omega_2^2 r_2 \cos \theta_2 \end{aligned} \quad (22)$$

For dynamic analysis of tri-star wheel by using complex numbers, the first step is to describe the free-body diagram. The second step is to create equilibrium equation based on free body diagrams. Furthermore, outlining all relevant vectors in the form of complex numbers.

Consider the free body diagram in Figure 7 the equilibrium equation is given as follows

$$\begin{aligned} \sum F &= \overline{mA_G} \\ \vec{F} + \vec{W} &= \overline{mA_G} \end{aligned} \quad (23)$$

Where the vectors described above as follows

$$\vec{F} = F_x + iF_y \quad (24)$$

$$\vec{W} = W e^{i\frac{3\pi}{2}} = -iW \quad (25)$$

$$\overline{mA_G} = mA_G (\cos \theta_{G2} + i \sin \theta_{G2}) \quad (26)$$

Then the equilibrium equation can be rewritten

$$F_x + iF_y - iW = mA_G(\cos \theta_{G2} + i \sin \theta_{G2}) \quad (27)$$

Components described in the real and imaginary components, generating the equation below

$$F_x = mA_G(\cos \theta_{G2}) \quad (28)$$

$$F_y = mA_G(\sin \theta_{G2}) + W \quad (29)$$

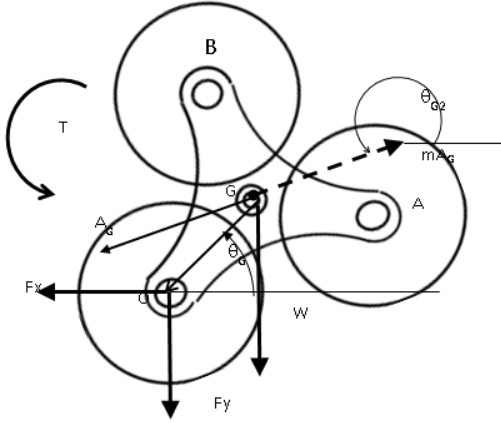


Figure 8. Tri-star wheel in equilibrium position.

In order to balance the system, then  $T = \vec{r} \times \vec{F}$ , where

$$\vec{r}_G = r_G e^{i\theta_G} = r_G (\cos \theta_G + i \sin \theta_G) \quad (30)$$

It can be shown as,

$$T = \begin{bmatrix} i & j & k \\ \vec{r} \cos \theta_G & \vec{r} \sin \theta_G & 0 \\ |F| \cos \theta_{G2} & |F| \sin \theta_{G2} + W & 0 \end{bmatrix}$$

$$T = \vec{r} \cos \theta_G * |F| \sin \theta_{G2} + \vec{r} \cos \theta_G * W - |F| \cos \theta_{G2} * \vec{r} \sin \theta_G$$

$$T = |F| * \vec{r} \sin(\theta_{G2} - \theta_G) + W * \vec{r} \cos \theta_G \quad (31)$$

### III. ANALYSIS MODEL AND DISCUSSION

#### A. Result of Model Analysis

From this research generated several things, among others:

- 1) Wheeled Mobile Robot (WMR) with Tri-Star Wheels are made visible in the image 11. This robot consists of a frame, tri-star wheel just as seen in Figure 12, the motor and transmission torque amplifier (Figure 13), and electronic devices.
- 2) Kinematic analysis of results of Tri-Star Wheels with kinematics equations by the method of complex numbers, give the values of position, velocity and acceleration of each points on the tri-star wheel as follows  $|r_A|$  and  $|r_B| = 0,18 \text{ m}$ ,  $|r_G| = 0,09 \text{ m}$ ,  $|V_A| = |V_B| = 0,195 \text{ m/s}$ ,  $|V_G| =$

$0,098 \text{ m/s}$ ,  $|A_A| = |A_B| = 0,216 \text{ m/s}^2$ , and  $d|A_G|$  is  $0,113 \text{ m/s}^2$ .



Figure 9. WMR Tri-Star

- 3) The results of the analysis of the dynamics of the wheel Tri-Star, is given in the graph in Figure 11. dynamic calculations to obtain the value of the torque to turn the wheels when climbing stairs.



Figure 10. Tri-Star Wheels

In the Figure 10, WMR Robot Products Tri-Star has a length of 110 cm, width 75 cm and height 60 cm. And for the tri-star wheel has a small gap between the wheel axis 18 cm and smaller wheelbase to the center tri-star wheels 10 cm.

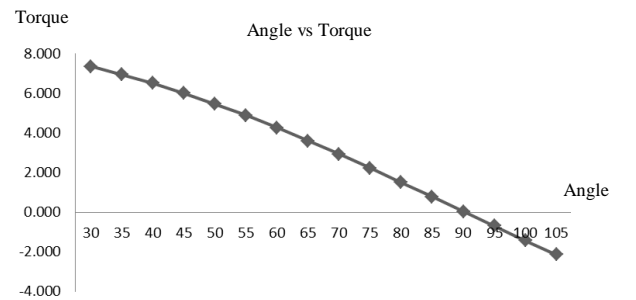


Figure 11. Relation between angle and torque

WMR Tri-Star robot is controlled by an open loop control system, wherein the command signal is given via an infra-red remote control system that is subsequently processed in the microcontroller and then proceed to the next motor controllers

motor will rotate according the applied voltage. Overall the controls are stored in a control box. From the observation, the command would be well received if the distance between the signal receiver remote with 1-10 meters.

From the test results, the performance of the robot WMR acquired Tri-Star is moving forward with a speed of 0.10 m / s, either moving backward with a speed of 0.10 m / s, turn left and right both with velocity 0.0024 rad / s, ladder that can be climbed up to a height of 20 cm and a width of at least 25 cm

#### IV.CONCLUSION

WMR robot by tri-star wheel can perform experiments for uneven surfaces. In addition, the tri-star robot successfully run straight, turn and climbs stairs. Meanwhile, the average of velocity of the Tri-star robot is 0.1 m / s. Furthermore, the controller of this system is done by open loop method using infrared control system.

#### ACKNOWLEDGMENT

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#### REFERENCES

- [1] Jufri, Sialana , Design Rescue robot for searching, Hasanuddin University, Makassar, 2010. (Original in Bahasa)
- [2] Hudan, Nuzula Alfian, Design Build Wheelchairs Can Be Up Stairs, ITS- Surabaya, 2010. (Original in Bahasa)
- [3] <http://www.tutorialgratis.net>, tutorial to create intelligent robots, 2010 (Original in Bahasa)
- [4] Sakti, Indra et. al, Driving force mechanism for soccer robot, Journal Information Technology (Journal in Bahasa), Vol. 5 No. 1, 2004
- [5] Santoso, Junaidi, "Design of Mobile Robot finder and obstacle avoidance using fuzzy logic control, Diponegoro University, Indonesia, 2009.
- [6] Stan, Gibilisco, Concise Encyclopedia of Robotics, McGraw-Hill, New York, Amerika Serikat, 2003.
- [7] Hutahaean, Y. Ramses, "Mechanism and Dinamics for Machine", Revision edition, ANDI Publishing, Yogyakarta., 2010 (Original in Bahasa)